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DISEASE AND TROPICAL INDUSTRY*

THE report of the meeting of the Advisory Committee of the Ross Institute held last year contains a valuable review by Dr. G. Macdonald of some of the diseases which interfere most severely with tropical industry. During the War, states Dr. Macdonald, the Army has learnt that, in the tropics, malaria is the most important cause both of incapacity and of the failure of whole projects. This is a lesson which tropical industry learnt years ago. New methods of tackling malaria have, however, been developed. The two main developments originated in pre-war civilian practice. These are the eradication of anopheline vectors rather than the attack upon malaria itself ; and the proof that the control of the adult mosquito is an economical as well as an effective method, which can be applied to rural communities at a cost which even the most primitive communities can bear.

The eradication of *Anopheles gambiæ* from Brazil during the years 1919–42 (1) showed that eradication of the vector from large areas of country is possible. A second campaign of a similar kind is now being carried out in Egypt, where *A. gambiæ* caused devastating epidemics of malaria in 1942 and 1943. We do not know when *A. gambiæ* first invaded the Nile Valley, but by 1943 malaria carried by this species was causing total disorganisation of large areas, very large numbers of deaths and so much illness that food production and distribution were hampered and famine was the result. The men who eradicated *A. gambiæ* from Brazil are now attacking it over an area of three hundred miles of the Nile Valley and there is every prospect of a success as brilliant as that which they achieved in Brazil.

Dr. Macdonald pointed out that the success of these anti-mosquito campaigns has been possible because re-invasion by the mosquito of the two areas concerned is difficult and can be prevented fairly easy, Brazil being guarded by the sea and Egypt by the desert ; the mosquito can be readily discovered in both its immature and mature stages ; there is a climatic off-season when the mosquito's breeding places are reduced in number, so that they can be more readily tackled; the organisation employed effectively co-ordinates the work in the different areas and is otherwise very efficient ; and sufficient money, men and time are freely made available. Dr. Macdonald thinks that these successes might be repeated in other areas,

*Article by G. Lapage reproduced from *Nature*, 157, 3985, 1946.

especially in such island areas as Mauritius and the Seychelles, where the anopheline species involved is the same one. In other areas, where different anopheline species are concerned, such as Ceylon and the West Indies, Malaya and Freetown, Sierra Leone, the conditions of success may be different, but the possibilities of eradication should be seriously considered. Russell and his colleagues have shown that systematic spraying of rural areas twice a week with various solutions and emulsions of pyrethrum can change, in two or three years, highly malarious areas into virtually non-malarious ones, the cost being no more than 3½*d.* per head per annual season of twenty-two weeks. Little more than ½*d.* per head of this cost was spent upon important products. Thus this method is within the means of the most poverty-stricken or primitive areas, provided that there is careful organisation and systematic application. This method does not, however, replace larval control where certain results are needed. D.D.T. will greatly lessen the labours involved in the control of the adult mosquito, but D.D.T. will not remove the greatest difficulty of malaria control, namely, adequate supervision. From the economic point of view, the use of D.D.T. as a larvicide is still in its experimental stage and it is not likely to be a great advance in the control of pool-breeding mosquitoes, such as those which are the chief vectors in Africa and Ceylon. On the other hand, D.D.T. can make it impossible for an aircraft to carry a live mosquito for a long journey, a fact which will help to minimize the transmission over large distances, not only of malaria-carrying mosquitoes, but also of those which transmit yellow fever.

Dr. Macdonald no doubt means it to be understood that D.D.T. can do this provided that its application to aircraft—and, indeed, to anything else—is efficiently and systematically carried out. His views may be compared with those expressed by the *Lancet* (2) in its discussion of the Government's Report on Colonial Research (3). The *Lancet* points out that C. B. Symes and A. B. Hadaway showed that, under suitable conditions, the mosquito population in houses can be almost completely annihilated by D.D.T. and that the number of larvæ in breeding grounds can be greatly diminished. It is, however, realized that the technical difficulties in the way of the effective and economical distribution of D.D.T. are very complex and that many years of team-work by chemists, engineers, entomologists and other experts will be needed before the value of D.D.T. for mosquito control can be correctly evaluated. Although, in addition, D.D.T. may prove to be a useful means of controlling other noxious arthropods, its indiscriminate use may also have serious effects upon arthropods which are useful to man in malarious areas. The kind of warning against the too-hasty use of D.D.T. for these purposes has been more than once expressed elsewhere. United States workers have, for example, pointed out that we do not yet know enough about the possible effects upon man of D.D.T. which has been sprayed upon crops for the control of insect pests. Nor do we know whether it is capable of exerting slow effects upon man and animals when it is incorporated in paints, varnishes and similar products. People who work with it and animals to which ointments containing it are applied may, however, under certain conditions be poisoned by it (4). V. B. Wigglesworth (5) has recorded a case of D.D.T. poisoning of an adult man, K. R. Hill and G. Robinson (6), a fatal case of poisoning of a child, and R. A. M. Case (7) also reports toxic effects and emphasizes the danger of D.D.T. in the presence of oil (8).

The Colonial Research Committee is also organising research upon the development of cinchona in East Africa, so that we may in the future be no longer dependent for the world's main supply of cinchona from Java, which was captured by the Japanese soon after her entry into the recent War. This capture, however, resulted in the development by the Allies of mepacrine (atebrin), which is now used as a prophylactic and curative anti-malarial drug and renders us independent of cinchona (9).

Discussing other anti-malarial measures, Dr. Macdonald said that highly organised destruction of adult mosquitoes by means of sprays applied with power syringes, and systematic treatment of all potential breeding places with hand-strewn Paris Green (that is, the methods used in the campaign in Brazil) completely effected rapid control of malaria for the purposes of the Eighth Army in Italy in 1944 within two days of the first occupation. The principles of the methods then used can, he suggested, be re-applied when we re-enter Malaya.

Dysentery is also one of the larger problems. The best means of preventing it is good sanitation, but this is not always possible, so that the remarkably successful abortive and curative effects of sulphanilylguanidine are invaluable. Like Sir Leonard Rogers and Sir John Megaw (10), Dr. Macdonald regards malnutrition as being "the bane of the tropics". It is good to know that the Colonial Research Committee is also organising an investigation of it. Dr. Macdonald also thinks that mite typhus (scrub typhus) may, as methods of cultivation of the land change, become more important in the tropics in the future.

Subsequent speakers at this meeting added their experience in industry to support Dr. Macdonald's views. It is evident from these speeches that the industrialist is well aware of the industrial need for, and the value to industry of, modern methods of control of disease. Brig.-General F. D. Hammond, indeed, said that hitherto the main support for tropical hygiene had come from commercial undertakings rather than from Governments. Tropical hygiene should, he thought, take priority over everything else because, unless the inhabitants are healthy, it is no use talking about development. Dr. Macdonald in his reply, pointed out that the Colonial Development and Welfare Act allowed for an expenditure of 120 million pounds during the next ten years, with a maximum expenditure of seventeen and a half millions in any one year. The Secretary for the Colonies had stated that part of this money would be spent

upon the development of health and education, and it was laid down that not more than one million in any one year should be spent upon research and inquiry of all kinds. Only a proportion of this sum, therefore, would go to medical research. Mr. C. R. Harrison, however, revealed that in Mauritius, at any rate, a "very large proportion" of the money received from the Colonial Development Fund will be devoted to hygiene and particularly to the control of malaria. It is to be hoped that other areas will copy this fine example.

1. *Nature*, *153*, 765; 1944.
2. *Lancet*, 311, 1945.
3. *H.M. Stationery Office*. Cmd. 6663. 6*d*.
4. *Lancet*, 320, 1945.
5. *Brit. Med. J.*, 517, 1945.
6. *Nature*, *156*, 780; 1945.
7. *Brit. Med. J.*, *842*, Dec. 15, 1945.
8. *Brit. Med. J.*, *27*, 1946.
9. *Nature*, *155*, 15; 1945.
10. "Tropical Medicine". London: J. and A. Churchill, 1944.

RESULTS OF CACAO EXPERIMENTS IN 1944-45

BY

E. E. CHEESMAN

FOLLOWING the procedure adopted last year (*Trop. Agriculture, Trin.*, 22 : 64–68) we present here a summary of results obtained from the field experiments of the Cacao Research Scheme in the crop year 1944–45. The data from these experiments have now accumulated to an extent which should permit conclusions to be drawn on several important questions concerning variation in clonal cacao and propagation methods. Discussion of those points, however, necessitates lengthy statistical analyses which cannot be completed immediately, and for that reason the emphasis in the present note is on gross yield.

The experiments concerned are those described in the Tenth Annual Report on Cacao Research (1940), pp. 3–11. Four of them, each comprising

Table I

Yields calculated as "lb. dry cacao per acre". Pod values as "pods to 1 lb. dry cacao".

Experiment and year of planting	Clone	Yield 1940-41	Yield 1941-42	Yield 1942-43	Yield 1943-44	Yield 1944-45	Aggregate yield since planting	Pod value 1944-45
CRB 1	ICS							
1937	1	88	148	645	739	895	2515	7.5
	3	21	14	36	113	210	394	7.8
	4	59	54	75	260	297	745	8.2
	5	19	10	34	85	234	382	6.7
	6	85	91	470	686	635	1967	5.8
	8	115	170	433	796	806	2320	7.8
CRB 2	ICS							
1938	1	–	75	591	326	937	1929	7.7
	7	–	6	38	119	349	512	7.3
	16	—	174	413	325	921	1833	7.6
	22	—	42	301	161	404	908	8.5
	45	—	177	548	306	855	1886	8.4
	53	—	56	294	214	721	1285	10.0
CRB 3	ICS							
1939	1	—	—	357	518	559	1434	8.7
	2	—	—	152	162	272	586	8.5
	9	—	—	100	172	213	485	8.5
	12	—	—	194	173	213	580	9.2
	60	—	—	347	658	653	1658	7.1
	98	—	—	249	515	460	1224	11.3
CRB 4	ICS							
1940	1	—	—	—	311	532	843	9.4
	44	—	—	—	124	356	480	10.8
	55	—	—	—	80	253	333	12.9
	70	—	—	—	97	277	374	10.5
	91	—	—	—	93	237	330	10.5
	95	—	—	—	279	526	805	13.3

576 pickets, were harvested monthly throughout the crop year 1944–45 (1st September, 1944 to 31st August, 1945), by Mr. W. H. C. Knowles.

Table I shows the yields for each year since recording began, and the aggregate yields from the clones to date. The figures given are calculated from the weights of wet cacao, recorded in the field in grammes per tree, taking the loss of weight in preparation as 60 per cent.

The table calls for little comment. The salient point is that, with minor fluctuations, all the clones are showing a fairly steady increase with age, and there appears no reason to suppose that any of them have reached their maximum. The six-year old block (CRB 2) has always looked better than the seven-year old CRB 1, and after an inexplicable "off year" in 1943–44 has given the highest average yet recorded—698 lb. per acre.

The clones are holding their relative positions as "good", "mediocre" or "poor" with remarkable consistency, and the differences between them are well brought out in the column showing aggregate yields since planting.

Pods were on the whole distinctly smaller this year than in 1943–44, the difference being most marked on the youngest trees, *i.e.*, in CRB 4. The pod value figures for ICS 1 at four different ages indicate that all the pod values in CRB 4 may be expected to improve as the trees get older. There is clear evidence from all our data that pod value (as would be expected) integrates effects of many factors, and until further studied it is a statistic of limited usefulness. It undoubtedly depends basically on genetical constitution, but is modified by age, season, number of pods on the tree at one time, and apparently also by rootstock influence among other environmental factors. These effects are among the questions upon which we hope to get further information when the full data have been analysed.

The differences between buddings and cuttings also need further analysis before any full discussion of them can be attempted. At present, and probably largely on account of the youth of the plantings, there is a high degree of variation from tree to tree even within clones, and consequently very considerable differences are necessary between means before statistical significance can be demonstrated. For what they may be worth, the results of 18 comparisons between cuttings and buddings are given in Table II. These comprise the clones in CRB 1, CRB 2, and CRB 3; those in CRB 4 being omitted because that set is still less regular in composition than the others with respect to age. For purposes of Table II, the total yield from the 96 pickets of each clone has been taken as 100, and the contributions of the 48 buddings and 48 cuttings respectively reduced to percentages.

It will be noticed that in 14 cases out of 18 the cuttings have yielded more than the buddings. In most cases the differences are almost certainly insignificant, or may be due to the cuttings being planted a month or two before the buddings; though there are one or two cases (notably that of ICS 8) in which significance will probably be found. Of the four cases where the buddings have yielded more than the cuttings, that of ICS 3 is clearly insignificant, and those of ICS 7 and ICS 12 possibly so. Only in ICS 2 is the difference remarkable, and here it is correlated with an abnormal amount of "supplying" that has been necessary with this clone. There are at present 17 cuttings of it less than 3 years old and only 2 buddings of similar age. The differential loss of cuttings may be significant, indicating a relatively weak root-system, and it is quite likely that ICS 2 is genuinely better when budded to a good rootstock than when on its own roots. But for immediate practical purposes the question is unimportant, because ICS 2 is but a mediocre clone at best (as also are ICS 7 and ICS 12).

Table II

Clone	Age	% of total yield	
		Buddings	Cuttings
1	7	44	56
1	6	48	52
1	5	40	60
2	5	62	38
3	7	51	49
4	7	37	63
5	7	42	58
6	7	45	55
7	6	55	45
8	7	35	65
9	5	40	60
12	5	55	45
16	6	46	54
22	6	44	56
45	6	43	57
53	6	47	53
60	5	46	54
98	5	40	60

It may be safely concluded that as far as our best clones are concerned, cuttings are certainly not inferior in performance to buddings, and in some cases they may be better. The conclusion applies, of course, only to trees up to 7 years old, as beyond that age we have no data. In a very few years more it should be possible to detect any trend of the differences to increase or decrease with age and thus to predict future performance.

The differences between fan and chupon material are on the whole still smaller, and provide no data for even tentative discussion at present.

In conclusion, the following notes on the most outstanding clones of the older plantings are offered:

ICS 1. The choice of this as the standard clone, against which others are compared, has proved to be extremely lucky, since ICS 1 has turned out to be the most generally satisfactory of all the clones tested. It is of good habit and medium vigour in vegetative growth, and in fruiting is a conspicuous example of a "continuous setter", being rarely without some fruit. The pod, containing on the average about 150 grammes of wet

cacao, is of good size and about average shell thickness. It is susceptible to Witches' Broom disease, like all the Trinidad selections, but within the range of variation shown in this respect by the ICS series it ranks as relatively resistant. This means that although in one month of specially heavy infection it lost 60 per cent. of its crop by disease (and in some circumstances could probably suffer 100 per cent. infection) yet in practice it loses a smaller percentage month by month than any clone in CRB 1 except ICS 6.

ICS 1 has already shown good performance on several soil types, and can be recommended for planting with considerable confidence.

ICS 6. This is specially noteworthy for its large pod, containing on the average nearly 200 grammes of wet cacao. Its total yield is distinctly below that of ICS 1, but still enough to put it in the first class. It has also the advantage of losing a relatively small percentage of its pods by Witches' Broom disease—usually slightly less even than the ICS 1. On the other hand it happens to be more infected with virus than any other clone in CRB 1 ; 36 trees are now infected out of 96, and this may be the reason for its failure to show better yields recently. ICS 6 is regarded as well worth further study, and clean material could be planted commercially without much risk of poor performance, but it cannot be regarded with the same confidence as ICS 1.

ICS 8. On total yield, there is little to choose between this and ICS 1. In absence of Witches' Broom disease ICS 8 would be the higher yielder of the two with us, as it produces more pods, but loses more than twice as many by this disease. The pods were slightly smaller than those of ICS 1 last year, but in some years have been slightly larger, and are not significantly different on the whole record. The relative susceptibility to pod infection is a weakness, which should not, however, be exaggerated. ICS 8 is undoubtedly a first class clone, suitable for commercial planting wherever Witches' Broom incidence is not particularly heavy.

ICS 16. This, as the table shows, has performed almost identically with ICS 1 in its own set, both in yield and in pod value. It has the same defect as ICS 8, losing nearly twice as many pods as ICS 1 by Witches' Broom ; and it also appears to be self-incompatible. Nevertheless its performance suggests that it should be profitable for commercial planting, and it might with advantage be planted in mixture with ICS 1 to ensure adequate fertilization.

ICS 45. This is a Nicaraguan Criollo cacao, and by standards applicable to that group shows a truly phenomenal performance. The trees never look very vigorous at River Estate, having rather hard, slender branches and a somewhat open canopy of narrow leaves. They may, under those conditions, prove short-lived ; but at present they still seem capable of increasing their yield. In a more favourable district even better results have been obtained. The loss of pods by Witches' Broom is extraordinarily small—considerably less as a rule than in ICS 1. As a self-compatible Criollo which can compete in yield with some of the best Trinitario clones, ICS 45 is of special interest and promises to be a most valuable clone both for commercial planting and as a parent in breeding.

ICS 60. This is also closely related to the Nicaraguan Criollo group, though a very different plant from ICS 45. It has a more vigorous vegetative growth, with its branches of a softer and more sappy texture, and with broader leaves. Its yield of 658 lb. per acre at four years old has not yet been equalled by any other clone, and failure to increase on this in the following year may fairly be ascribed to temporary exhaustion. At the same time (in 1943–44) the pods averaged 164 gm. of wet cacao, and the beans are large. Defects in ICS 60 are self-incompatibility and a high rate of cushion infection by Witches' Broom disease, but the pod loss has not been unduly high, and as long as the clone maintains anything like its present performance it is particularly worthy of close observation and commercial trial. It may perhaps prove suitable for growing in mixture with ICS 45.

ICS 98. This is in a different class from the rest, its outstanding character being that it is a prolific bearer of small pods. The pods may improve a little with age, but at the present average only just 100 grammes of wet cacao, which is far below our standard though about the average for seedling cacao in Trinidad. It is a vigorous grower, easy to establish, and probably self-compatible though not yet fully tested. ICS 98 is not recommended for general planting whilst its quality is in some doubt (on account of the small pod and beans) but it may prove a profitable clone for districts where hardiness is specially desirable, and larger-fruited types are not successful. It at least merits careful observation.

ERRATA

March, 1946 issue, p. 49, column 2, under heading *Explanation of Diagram :*

Line 12: For "between 0.75 and 0.40 ins. per hour" *read* "between 0.75 and 0.41 ins. per hour".

Line 16: For "intensity below 0.40 ins. per hour" *read* "intensity below 0.41 ins. per hour".

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THE EVALUATION OF SOIL MOISTURE

Results of the Application of Some Suggested Methods for Assessing "Effective Rainfall" to Experimental Data

BY

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(I) Introduction

In a previous article*, periodic data for the moisture and nitrate contents of soil comprising fallow, cropped and pasture plots at the College Farm were presented and discussed in relation to fluctuating rainfall over the greater part of three wet and three dry seasons. An attempt was made to interpret the soil moisture data in terms of "effective rainfall" (that is, that part of the rain which penetrates into the soil and is stored within the rooting zone of plants) and of physical soil constants. It was found that, during the dry season, as the soil dries out into the capillary range approaching wilting point, nitrate tends to accumulate in considerable quantity, but that, during the wet season, when the soil is progressively wetted by rain up to field capacity and further, up to saturation capacity, nitrate first diffuses and is then leached out of the rooting zone and lost in the drainage. The practical significance of these findings was discussed.

The study of soil moisture relations comprises the most important part of ecological crop investigations, and the determination of moisture contents of soil samples periodically collected in the field usually forms an essential part of such investigations. It can only be carried out satisfactorily, however, in plots or fields in the vicinity of the laboratory, since no convenient method for accurately measuring soil moisture contents out of doors has been devised. It should nevertheless be possible to derive soil moisture contents from daily rainfall records, provided suitable and reliable relationships are first established between total and effective rainfall as defined above. This would eliminate the necessity for determining soil moisture contents directly and would thus prove of great service in the study of soil moisture conditions in remote areas, or for lapsed periods of time during which soil moisture contents had not been directly measured.

In the first article, a preliminary attempt was made in this direction by considering the penetrating capacity of different arbitrary categories of rain showers, based on a scheme of rainfall classification used in Queensland, Australia. In this scheme, only medium showers which fall at a rate lying between 0.75 and 0.41 inches per hour are regarded as capable of penetrating into the rooting zone and thus becoming effective for crop growth. Showers of greater intensity than this are presumed not to penetrate, since rain water of this category probably all runs away off the land. Similarly, showers of lesser intensity fail to penetrate because this rain water completely evaporates from the soil surface or vegetation-cover and is completely lost.† It was found that, within the College area, only about 20 per cent. of the total rain falls as medium or penetrating showers, of which there are between 30 and 60 in a wet season and 15 to 20 in a dry season. Rain falling at the medium rate was observed to cause downward movement of accumulated nitrate at the beginning of a wet season, and was thus amply sufficient to maintain the moisture content of the soil above field capacity for long periods of time. According to the magnitude of the soil's physical constants, only 4 to 7 successive medium showers would be required for complete saturation, starting from wilting point, and only one medium shower would be required to raise its moisture content through the whole range of observed fluctuation. Evidently therefore a large proportion of the medium rain that infiltrates into the soil surface penetrates deeply beyond the rooting zone, carrying soil nitrate with it out of reach of absorbing roots.

It follows from these considerations that the mere evaluation of the quantity of medium-shower rain that falls on an area of land cannot provide a reliable measure of the effective rainfall though it may approximate to the *total* amount of rain which soaks into the soil, of which only part becomes

* Hardy, F. (1946). Seasonal fluctuations of soil moisture and nitrate in a humid tropical climate (Trinidad, B.W.I.); *Trop. Agriculture, Trin.* **23** : 40-49.

† Davidson, quoted by Moreau (*Journ. Ecol.*, 1938, **26,** p.478), considers that, for New South Wales, Australia, "only rains amounting to 0.20 ins. do real good in an agricultural way". Also that, "in "the dry north of South Australia, an ecologically-"effective rainfall is one consisting of 0.15 ins. or "more, and which falls during a distinct rainy period; "on the other hand, in a dry period, 0.25 ins. is "nearer the minimum effective...., lighter falls do "not penetrate the soil more than 2 or 3 cm.". Moreau maintains, however, that for low altitudes in East Africa, this estimate (0.25 ins.) is too low. On the other hand, the limit provisionally accepted by us (0.41 ins.) is probably somewhat too high for the College area, because when the soil is permanently damp, as it is during the wet season in Trinidad, even light showers might suffice to maintain a high moisture status. At the same time, torrential showers might the more readily be shed under these conditions. During the dry season, as the soil loses water and air enters the smaller pore-spaces, even medium showers, as well as torrential downpours, if any, may fail to penetrate, because of the difficulty of dislodging soil gases.

really effective, the rest penetrating deeply beyond the rooting zone, depending on the finite limits of that zone.

In the following sections, another method for estimating the amount of rain water that evaporates from the soil surface will be examined, since this quantity partly determines the magnitude of the effective rainfall and thus largely decides the ecological aridity, or its converse, the ecological humidity of the soil environment. In addition, a method for assessing effective rainfall from daily rainfall records will be considered, and an attempt will be made to apply it to collected rainfall data available at the College, and to check the results against actual values for soil moisture content and for amount of water lost by surface evaporation.

(II) The Fate of Rainfall: General Considerations

The problem of what happens to the rain when it falls on the land is fundamental in crop ecology though difficult, if not impossible, to solve completely. The simplest quantitative relationship between the main factors involved is given by the equation :—T=E+R+F+D,

where
- T=total rainfall, in inches or millimeters,
- E=evaporated water,
- R=run-off water,
- F=effective rainfall,
- D=deeply penetrating water.

Direct measurement: Of these factors, T, R and F may be measured directly and relatively easily in the field, T by means of a rain gauge, R by setting up on the land side-guards or barriers which direct run-off water into suitable collecting vessels, and F by weighing and drying representative soil samples taken to appropriate depth, usually to the base of the main rooting zone. On the other hand, factor D can only be measured directly *in situ* by excavating the subsoil from beneath a plot of land and collecting the water that percolates through the roof, as in the lysimeter. The factor E cannot easily be measured directly in the field; it is therefore usually evaluated from the magnitudes of the other four factors by difference. Nor is it sufficient to rely on determinations of evaporation from a free water surface by the use of an evaporimeter or atmometer as a means of assessing soil evaporation because evaporation is retarded when moisture is soaked up into a soil so that the results obtained would be too high.

Evaporation from soil, however, may be directly determined experimentally in cylinders of soil collected with as little disturbance as possible and set up out of doors. The cylinders are furnished with notched rims for collecting run-off water and also with funnels for catching drainage water. By this means, not only may evaporation be evaluated with some degree of accuracy but the effect on evaporation of a cover of vegetation of various kinds and of soil crumb, litter or humified organic matter may also be traced. In these experiments, the quantity of effective rainfall, that is, the gross soil moisture content, may remain fairly constant near field capacity.

Dynamic concepts: For the purpose of most ecological studies, the simple quantitative assessment of the component fractions into which rainfall theoretically may be subdivided is not enough. The effects of fluctuations in the rainfall must also be considered since, in actual fact, rainfall is seldom steady for long periods. Thus, for constant soil permeability, the amount of run-off increases directly as the total rainfall increases above a certain limiting value representing the maximum percolation capacity of the soil under investigation. Thus it is necessary to know the actual *rate* at which the rain falls, as well as the rates at which part of it evaporates, part runs away and part percolates, if a true portrayal of soil moisture relationships is desired.

Rates of rainfall may conveniently be deduced from the tracings of a recording rain gauge. The different showers may subsequently be arbitrarily classified in accordance with their rates of fall, as outlined in the Introduction. Similarly, the rates of run-off and of percolation may also be determined from regular periodic measurements preferably obtained by means of self-recording instruments. Where experimental cylinders of soil are used, evaporation rates may be directly determined in similar manner, as a check on differential results, by continuous weighing, employing an automatic balance for the purpose.

Effective rainfall: As previously defined, effective rainfall (F) is that fraction of the total rainfall (T) which gains access to and is stored in the soil comprising the rooting zone of a crop. This definition will be accepted in the sequel. Certain writers use the term, however, to mean the whole residue of water which soaks into the ground and which, together with evaporated and run-off water, comprise the total rainfall. Others use it to denote "available" soil moisture, that is moisture content above the wilting point. Here, the water which percolates downward out of reach of roots will be regarded as "deeply-penetrating" water (D) and considered separately. The quantity of effective rainfall that is stored in the rooting zone depends on the physical features of the soil and these may differ appreciably in different soil-types.

(III) The Estimation of Water Evaporated from the Soil Surface: Mohr's Method

The method of evaluating evaporated water so far considered depends on a conventional classification of rain showers into "torrential", which are assumed to run off the land, "medium" which soak into the ground, and "light" which represent the evaporated water. The limits of each category which may tentatively be accepted must first be repeatedly checked by comparison of results with those obtained by other methods before they can confidently be applied to general ecological problems. A promising comparative method

which might be used for this purpose is that suggested by Dr. E. C. Julius Mohr* ; this will now be described.

Mohr's method for evaluating evaporated water: In this method the amount of water evaporated from a soil is estimated by the application of a formula which was derived by Dr. E. C. Julius Mohr from experimental results obtained at Buitenzorg in Java. Metal cylinders, 0.5 m. diameter and 0.5 m. deep, containing volcanic ash soil ("Yellow Earth"), were set up out of doors in the vicinity of a standard rain gauge and an open-pan evaporimeter. Arrangements for collecting run-off water and percolating water were provided as described in an earlier section.

The mean total annual rainfall at Buitenzorg is 168 ins. It was found that, in an average year, 44 ins. run off the surface and 76 ins. percolate through the soil, so that 48 ins. of rain must evaporate. The open-pan evaporimeter, which was fully exposed to wind and sunshine but shielded from rain, gave markedly different results for the amount of evaporation as compared with those obtained with cylinders of soil. The values were generally much higher except during the four rainiest months when the soil was completely saturated with water, in which case the amount of evaporation from the soil rose to about 97 per cent. of that from the free water surface. It was also found that the amount of evaporation from the soil increased directly as the rainfall increased. A formula connecting the two quantities was finally deduced from several years' data, namely,

$E = 2.4\ 1/8R$, where E=evaporated water, and R=monthly rainfall.

In this formula, E and R are expressed as *inches* of monthly rain.†

Mohr rightly points out that this formula strictly applies only to areas whose climate is similar to that at Buitenzorg where the total annual rainfall is not only very high (168 ins.), but is distributed between a severe wet season of seven months' duration having mean monthly rainfall 16 ins. and a drier season having mean monthly rainfall less than 10 ins. During the wet season at Buitenzorg, between 5.6 and 3.8 ins. of rain evaporate per month from the soil and during the drier period, between 3.7 and 3.2 ins. evaporate. On the basis of these facts, Mohr proposes to designate as "*arid*" those tropical climates having mean monthly rainfall less than 2.4 ins. when rain is rapidly evaporated and so cannot soak into the ground, and "*humid*" those climates having rainfall over 4.0 ins. a month so that most of it penetrates deeply. Support is given to Mohr's contention by the independent evaluation of the critical evaporation constant by other investigators (for example, de Martonne (1909) and Köppen (1916))who have also arrived at figures approximating to 2.4 ins. per month.

No experimental data for water-loss by evaporation from the surface of the soil have yet been procured in Trinidad, but it is possible by applying the results obtained by Mohr to obtain an approximate measure of what it is likely to be over the College experimental plots.

In the first column of Table I are given the monthly rainfalls (R) in inches for the typical year 1908 at Buitenzorg, as recorded by Mohr. The values are arranged in decreasing magnitude for the wet and for the dry seasons. The second column gives the corresponding values for amount of water (P) evaporated from an open pan set up near the rain gauge. In the third column are given the experimentally-determined values for amount of water (E) actually evaporated from the surface of a cylinder containing undisturbed uncropped Yellow Earth soil. Provision was made for the collection and measurement of drainage and run-off water ; evaporated water was then estimated as the difference of their sum from the total rainfall as already described. In the fourth column, the ratios of E to P are given as percentages.

It will be seen in Table I, that for the wettest months of the 1908 wet season when the rainfall was over 15 ins., practically as much water was evaporated from the soil surface as from a free-water surface. For the relatively dry months in the wet season and for all months in the dry season, only about 60 per cent. of the amount of water evaporated from a free surface was actually evaporated from the moist soil.

Application to data obtained at the College: Data for the College Farm plots are also set out in Table I for an average year, 1935. It will first be noted that no monthly rainfall (Column 5) was as high as 15 ins., so that, unlike the results obtained in Java, the amount of water evaporated from the soil surface must throughout have been considerably less than that lost from a free-water surface. In Column 6 are given the quantities of water actually lost from a free-water surface as measured by a battery of Livingston white bulb atmometers calibrated against an open-pan evaporimeter. By selecting appropriate percentages from the range of ratio values obtained in the Java experiment as set out in Column 4, a rough estimate of the amount of water evaporated from the soil surface of the College plots may be deduced. The selected ratios are given in Column 7; admittedly they are only an approximation, but they are believed to be not very far from the truth.

* "Soils of Equatorial Regions", E. C. J. Mohr, Ann Arbor, Michigan, U.S.A., 1944, pp. 53-54

† According to de Martonne's "index of aridity" as applied by Andrews and Maze in Australia, a "dry" month is one in which the rainfall (in mm.), divided by temperature (C°+10), is numerically less than unity. A wider limit was independently suggested by Scaëtta for the Belgian Congo, namely, 1.66 instead of 1.00. On this last basis, dry months at the College would be those having rainfalls less than $1.66 \times (28+10)$ °C., or 63 mm. or 2.5 inches. This may be compared with the figure 2.4 ins. derived by Mohr. *See* R. E. Moreau, *Journ. Ecol.*, 1938, **26**, p.478.

The final values for "probable water evaporated" from the College soil are given in the last column of all. The texture and porosity of the College plot soil is judged to be similar to that of the Java volcanic-ash Yellow Earth, so that Mohr's method of calculation may be applied to the derived data. When the values for probable amount of water evaporated are plotted against monthly rainfalls at the College, their numerical relationship is found to fit the formula, $E=4.0+1/8R$ (ins.). This implies that monthly rainfalls less than about 4 ins., evenly distributed, fail to penetrate into the soil of the College plots, but are lost by evaporation from the soil surface. This value is indeed identical with that finally adopted by Mohr, "for safety's sake", as the critical value for water penetration in Java. It may therefore tentatively be accepted and applied to the College rainfall records for demarcating "arid" months when the effective rainfall is negligible, from "humid" months when its magnitude is finite. For the average year 1935, five months would be classed as arid and seven as humid. In contrast, there were four arid months in 1933 and 1936, and eight in the exceptionally dry year 1934.

Comparison between evaporated water (A) evaluated as "light" showers and (B) derived from Mohr's formula—If all the rain water that falls as light showers of intensity rating 0.40 ins. per hour or less evaporates without penetrating, then its amount should have the same order of magnitude as that estimated from Mohr's formula which is based on actual evaporation measurements. In Table II comparable data for the College Farm plots are brought together to test this relationship for the period of the investigation.*

* *Note*:—It is fully realised that this elementary treatment of the data is at best only likely to yield approximate results, but it is justified on the grounds that it may lead to a reasonable evaluation of the amount of water that penetrates into the soil. The extremely complicated process of water evaporation from variably-wetted soil has been investigated at Rothamsted by H. L. Penman and R. K. Schofield (*Journ. Agric. Sci.*, 1941, **31**, pp.74-109) and by H. L. Penman (*ibid.* pp.454-465; see also, *Quart. Journ. Roy. Meteorol. Soc.*, 1940, **66**, pp.401-410), and more recently at Ottawa, Canada, by W. J. Staple and J. J. Lehane (*Soil Sci.*, 1944, **58**, pp. 177-193), who have adduced a series of diagrams and equations for its computation from meteorological data.

Table I

Comparison of Evaporation Data: Buitenzorg (Java) and I.C.T.A. (Trinidad)

1	2	3	4	5	6	7	8
Buitenzorg; Java, 1908				I.C.T.A.; Trinidad, 1935			
Monthly rainfall	Evaporation		Ratio	Monthly rainfall	Evaporation Open pan	Derived Values	
	Open pan	Soil surface	$\frac{E \times 100}{P}$			Probable ratio, $\frac{E \times 100}{P}$ %	Probable soil evaporation (E) (ins.)
(R) (ins.)	(P) (ins.)	(E) (ins.)	%	(R) (ins.)	(P) (ins.)		
Wet Season							
25.0	6.0	5.6	93.3	13.8	6.9	80	5.5
23.0	5.6	5.4	96.4	13.7	5.6	80	4.5
21.1	5.6	5.4	96.4	7.7	7.4	70	5.2
14.9	4.3	4.1	95.3	6.2	6.3	65	4.1
14.8	4.8	3.8	79.2	5.6	8.4	64	5.4
9.7	6.0	3.8	63.3	5.1	7.8	63	4.9
7.6	5.9	4.1	69.5	3.8	9.3	50	4.7
Means							
16.6	5.5	4.6	84.8	8.0	7.4	67	4.9
Dry Season							
15.7	5.8	3.4	58.6	6.1	9.0	(65)	(5.8)
10.9	5.9	3.7	62.7	0.9	12.4	5	0.6
10.4	5.4	3.4	62.9	0.7	8.7	5	0.4
9.7	5.8	3.6	62.1	0.5	8.7	5	0.4
5.4	6.1	3.2	52.5	0.3	13.8	5	0.7
Means							
10.4	5.8	3.5	59.6	1.7	10.5	(5)	(0.5)

Total rainfall: Wet season 116.1 ins. (Java) 55.9 ins. (Trinidad).
Dry season 52.1 ins. 8.5 ins.

Whole year 168.2 ins. 64.4 ins.

For wet season months whose rainfall exceeds 4 ins., the data in Table II show a fair agreement between the two methods for evaluating evaporated soil water, but the agreement is naturally very poor for dry season months having rainfall less than 4 inches. The data for evaporated water determined as light showers show greater fluctuations than those estimated from Mohr's formula, as would naturally be expected. According to the figures, nearly 60 per cent. of the total rainfall during the wet season is lost by evaporation before it can penetrate far into the rooting zone, but during the dry season almost all is lost by evaporation and very little penetrates.

The wet season of 1934 was the driest of the four years of the investigation; a monthly average of only 6.5 inches of rain fell during that period and the rainfall for each of the first four wet months was well below the general mean for those months; nevertheless, the proportionate amount of wet season rain that fell as light showers was approximately the same as for the other three much wetter years.

(IV) The Derivation of "Effective" Rainfall from Daily Rainfall Records: Leake's Method

Effective rainfall has been estimated by several investigators by applying a proportionality factor to the rainfall data whereby the amount of rain water that is likely not to be lost is approximately assessed. This principle underlies the procedure elaborated by Dr. H. M. Leake which will next be described.*

Leake's method for evaluating "effective" rainfall: This method is based on the arbitrary assumption that, of the total quantity of rain that falls on any particular day, one-twentieth is lost, and, of the remaining nineteen-twentieths, a like fraction is similarly lost on the second day, leaving a residue to which is added the amount of rain that may fall on the second day, and so on. The successive daily fractions that are lost are considered to represent "run-off, percolation, evaporation and "transpiration, as well as the moisture held in the "soil in the un-free condition" (*sic*). Leake considers that the selected fraction, one-twentieth, which evaluates the magnitude of the daily loss, "is one which satisfies a considerable range of "soils in the Tropics" (*sic*). The residue of water must therefore represent what has been termed in our previous article, "available soil moisture" that is, gross soil moisture content *minus* the wilting coefficient of the soil, expressed as weight percentage on oven-dry material. The definition of effective rainfall as accepted by Leake is thus not quite the same as that proposed in this article which is identical with the definition of "gross soil moisture content". It differs from ours in that it does not include "un-free" water below the wilting coefficient level, representing moisture that cannot be abstracted from a soil by plant roots.

The application of his method enabled Leake accurately to forecast the yields of wheat and cotton in the Cawnpore District of Northern India, of cotton in the Bombay Presidency of Western India, and of sugar-cane in Barbados, so that it evidently covers quite a wide range of conditions.

The data obtained by Leake's method for water lost differ essentially from those obtained by the shower-category method and by Mohr's method in that they are continuous and cumulatively linked. They thus lend themselves to simple graphic representation by continuous lines, whereas the data derived by the other two procedures, being discontinuous, are amenable to simple graphical representation only by vertical columns or vertical lines. Devices such as the calculation and plotting of moving averages applied to such discontinuous data, although they may partly smooth out the irregularities, yet do not involve a "carry-over" from one day to the next which is the essential feature of Leake's procedure.

Hence they fail to effect an appropriate adjustment essential for strict comparison of results yielded by the other essentially different continuous methods of evaluation.

The chief criticism of Leake's method is that the rate at which his effective rainfall diminishes during dry periods appears to be unduly slow. Thus, an accumulation of two inches of effective rain within the soil would still be nearly half-an-inch effective after 30 days of continuous drought. Moreover, all rain showers, no matter how light or how heavy, are similarly treated; for example, a rainfall of two inches in part of a day (not unusual in Trinidad) would be regarded as 1.90 ins. effective on the next day, which is hard to reconcile with practical experience of the behaviour of soils under the impact of heavy showers when run-off may account for practically all of the rain that falls.

It is therefore doubtful whether run-off water should actually be included in the fraction lost and whether it would not be more reasonable to subtract from the daily rainfall figures all rain that has fallen as torrential showers of intensity greater than some arbitrary critical value to be agreed upon, for example, 0.75 ins. per hour as in the Queensland classification.

Soil moisture constants.—Leake's procedure fails to take into account the fact that there is an upper limit to the capacity of a soil to absorb and retain water. For a free-draining soil, there are two important moisture constants that are involved in water absorption and retention, namely, maximum or saturation capacity and free storage capacity when thoroughly drained, that is, field capacity. The magnitude of the first is decided by the total pore-space of the soil, that is, both macro or non-capillary pore-space and micro or capillary

* H. Martin Leake:—"Agricultural value of rainfall in the tropics," *Proc. Roy. Soc.*, B., **103**, p.82, 1928; also, "Moisture requirements of tropical crops", *Emp. Cotton Growing Rev.*, **5**, pp.212-227, 1928, and "Rainfall and crop conditions", *Trop. Agriculture, Trin.*, **6**, pp.43-45 and pp.74-77, 1929.

Table II

Comparison of Two Indirect Procedures for Evaluating Evaporated Soil Water

	1933				1934				1935				1936			
		Evaporated				Evaporated				Evaporated				Evaporated		
	Total Rainfall (ins.)	(A) Light showers (ins.)	(B) from Mohr's formula (ins.)	Difference (A)-(B)	Total Rainfall (ins.)	(A) Light showers (ins.)	(B) from Mohr's formula (ins.)	Difference (A)-(B)	Total Rainfall (ins.)	(A) Light showers (ins.)	(B) from Mohr's formula (ins.)	Difference (A)-(B)	Total Rainfall (ins.)	(A) Light showers (ins.)	(B) from Mohr's formula (ins.)	Difference (A)-(B)
WET SEASON																
June ...	12.42	7.56	5.55	2.01	1.08	0.97	(4.13)	−0.11	3.79	1.84	(4.47)	−1.95	12.79	8.21	5.60	2.61
July ...	12.53	7.28	5.57	1.71	3.80	2.98	(4.47)	−0.82	7.75	3.79	4.97	−1.18	10.68	7.40	5.33	2.07
August ...	11.16	5.23	5.40	−0.17	7.30	3.17	4.91	−1.74	13.74	7.00	5.72	1.28	10.38	3.69	5.30	−1.61
September ...	12.33	5.88	5.54	0.34	6.80	3.33	4.85	−1.52	13.76	9.81	5.72	4.09	9.67	5.16	5.21	−0.05
October ...	8.22	2.07	5.03	−2.96	11.05	6.09	5.38	0.62	5.56	2.04	4.69	−2.65	5.13	1.73	4.64	−2.91
November ...	7.68	4.93	4.96	−0.03	11.75	9.85	5.47	4.38	6.25	4.01	4.78	−0.77	8.73	4.06	5.09	−1.03
December ...	9.51	7.64	5.19	2.45	4.05	2.41	(4.51)	−1.64	5.09	3.82	4.64	−0.82	6.88	5.34	4.86	0.48
	73.85	40.59	37.24	3.55	45.83	29.00	29.54	−0.54	55.94	32.31	34.31	−2.00	64.26	35.59	36.03	−0.44
DRY SEASON																
January ...	4.11	4.00	(4.51)	−0.11	1.73	1.73	(4.22)	0.00	0.74	0.74	(4.09)	0.00	2.35	0.63	(4.29)	−1.72
February ...	0.74	0.53	(4.09)	−0.21	0.83	0.83	(4.10)	0.00	0.51	0.51	(4.06)	0.00	1.00	0.95	(4.12)	−0.05
March ...	1.23	1.00	(4.15)	−0.23	0.47	0.47	(4.06)	0.00	0.93	0.89	(4.12)	−0.04	0.45	0.12	(4.06)	−0.33
April ...	1.74	1.61	(4.22)	−0.13	0.16	0.16	(4.02)	0.00	0.28	0.19	(4.03)	−0.09	2.32	1.10	(4.29)	−1.22
May ...	5.68	3.33	4.71	−1.38	1.49	1.39	(4.19)	−0.10	6.07	4.67	4.76	−0.09	6.57	3.47	4.82	−1.35
	13.50	10.47	12.53	−2.06	4.68	4.58	4.68	−0.10	8.53	7.00	7.22	−0.22	12.69	6.27	10.94	−4.67
Total ...	87.35	51.06	49.77	1.29	50.51	33.58	34.22	−0.64	64.47	39.31	41.53	−2.22	76.95	41.86	46.97	−5.11

Note.—Brackets denote values for estimated evaporated water greater in magnitude than total rainfall; evaporated water in these cases is assumed to be equal to total rainfall.

pore-space, including the minute vesicles that occur in the reticulate soil colloids. The magnitude of the second is decided by micro-pore space alone; it is approximately equal to the index of texture value which is mainly decided by the quantity of colloidally-bound water present. Thus when the accumulated effective rain-water exceeds in magnitude the field capacity constant of the soil, percolation will remove the excess unless the rate of accumulation exceeds the rate of removal in which case the soil-pores will fill up with water to saturation capacity. Air will be expelled in the process and the roots of growing plants will be increasingly subjected to asphyxiation. The three modifications in the application of Leake's method mentioned above will be applied to the actual experimental data now to be presented and discussed.

Comparison between effective rainfall estimated by Leake's method and available soil moisture content determined directly: During the investigation described in the previous article, gross soil moisture contents were determined approximately monthly in three duplicated plots, fallow, cropped (to maize) and pasture (savanna grass) over the greater part of three wet seasons and three dry seasons during the years 1933-1936. Top soil (0-4 ins.) and sub-surface soil (4-10 ins.) were sampled separately for soil moisture determinations, which were carried out in the laboratory situated near the plots. At a later date, various physical soil constants were determined in the laboratory and in the field so that the soil moisture values could the more readily be interpreted. The essential data are brought together in Table III.

Table III

Physical Constants needed for Interpreting Soil Moisture Data

College Farm Plots: Combined topsoil and sub-surface soil; 0-10 ins. total depth.

Soil constant	Weight per cent.	Volume per cent.	Equivalent inches of rain for 10-ins.layer
Wilting coefficient ..	9.3	12.6	1.26 ins.
Field capacity ..	15.2	20.6	2.06
Saturation capacity ..	30.0	40.6	4.06

Note.—The total pore-space of the soil down to the 10-inch depth averages 40.6 per cent. of the volume of water-free soil; this sets the upper limit of water absorption, *i.e.* the saturation capacity. The index of texture value is 15.2 per cent. by weight, derived from mean sticky point value, 29.2 per cent., corrected for water-films by subtracting one-fifth of the sand content which is 70 per cent; *i.e.* 29.2 *minus* 14.0. This roughly determines the field capacity. Finally, wilting coefficient, 9.3 per cent. by weight, was measured directly in soil cultures of maize seedlings as in the standard method. Weight percentages may be converted to volume percentages by multiplying by the apparent specific gravity of the soil which was determined on constant volume samples obtained with little disturbance in the field and found to be 1.353.

Discussion.—It will be seen in the last column of Table III that the first 1.26 ins. of rain water added uniformly to the perfectly dry soil would be "un-free" and not available to the growing plant. The further addition of 0.80 inch of rain water would be sufficient to raise the moisture status of the soil through the full capillary range in which it is freely available to plants without risk of lack of aeration. The addition of 2.00 inches more would completely fill the non-capillary pore spaces so as to saturate the soil with exclusion of air. Other additions over and above the total amount, 4.06 inches of rain, would flood the soil and run away unless the rate of deep percolation was adequate to keep pace with the incidence rate of the rainfall which would probably not be the case for torrential rain showers.

In Table IV are set out in parallel columns values in inches of rain for (*a*) total effective rainfall, and (*b*) effective rainfall when torrential rain is discarded from the daily rainfall records, derived by the application of Leake's formula. These values are to be compared with those of Leake's effective rainfall (available soil moisture) derived from gross soil moisture contents, directly determined on the field samples, by subtracting the value for wilting coefficient. These too are expressed as inches of rain. The results are set out as graphs in the diagram at the end of this article.

Discussion.—It will be noted that the actual values for available soil moisture (Leake's effective rainfall) have in general much lesser magnitude than those for effective rainfall derived by Leake's method from daily rainfall figures uncorrected for torrential showers. On the other hand, they agree fairly closely with those derived by Leake's method from the *corrected* daily rainfalls. The similarity of the graph-shapes for corrected rainfall and for available moisture is very striking, particularly the graph for the fallow plot where complications introduced by the presence of growing plants are absent.

The differences (surpluses) are set out in the table. Their mean values for wet seasons and for dry seasons are shown at the foot of the table. For the fallow plot, the slight excess of the calculated effective rainfall for wet seasons is about equal to the deficit for dry seasons. In the cropped plot, the surplus is greater, but for the pasture plot a deficit is shown for all seasons. Evidently, even when corrected for torrential showers, the calculated or theoretical effective rainfall is somewhat higher than the actual available moisture content during wet weather and a little lower during dry weather.

The degree of correlation between corrected effective rainfall, calculated by Leake's method and available moisture, experimentally determined is high, the correlation coefficient being 0.709 which is significant at the 0.1 per cent. point.

Table IV

Comparison of "Effective Rainfall" with Available Soil Moisture Contents

(Top and subsurface soils combined)

1	2	3	4	5	6	7	8	9	10
No.	Week	Effective rainfall		Fallow		Cropped		Pasture	
		Total (ins.)	*Minus* heavy showers (ins.)	Total water (ins.)	Surplus (ins.)	Total water (ins.)	Surplus (ins.)	Total water (ins.)	Surplus (ins.)
Wet Season		1933							
1	0	4.90	1.90	2.14	−0.24	1.74	0.16	—	—
2	10	3.16	2.47	2.19	0.28	2.26	0.21	2.59	−0.12
3	12	2.03	1.69	2.01	−0.32	1.88	−0.19	2.20	−0.51
Dry Season		1934							
4	18	0.63	0.59	1.19	−0.60	0.72	−0.13	0.71	−0.12
5	22	0.24	0.24	0.63	−0.39	0.62	−0.38	0.48	−0.24
6	29	0.89	0.67	0.70	−0.03	0.65	0.02	1.31	−0.64
7	37	1.72	1.28	0.96	0.32	0.97	0.31	1.77	−0.49
Wet Season									
8	47	3.65	1.86	2.28	−0.42	2.51	−0.65	3.06	−1.20
9	50	5.86	2.76	2.66	0.10	2.55	0.21	1.98	0.78
10	53	6.35	(3.62)	2.43	1.19	2.58	1.04	2.56	1.06
11	55	8.42	(6.10)	2.86	3.24	2.73	3.37	2.67	3.43
12	58	4.96	(2.90)	2.19	0.71	1.71	1.19	2.32	0.58
Dry Season		1935							
13	63	1.11	0.93	1.32	−0.39	1.39	−0.46	0.97	−0.04
14	66	0.72	0.68	1.35	−0.67	1.45	−0.77	1.68	−1.00
15	70	0.44	0.37	1.02	−0.65	0.48	−0.11	0.43	−0.06
16	76	0.40	0.29	0.82	−0.53	0.38	−0.09	0.65	−0.36
17	78	0.71	0.28	0.63	−0.35	0.34	−0.06	0.00	0.28
18	81	2.54	1.21	1.13	0.08	1.04	0.17	0.93	0.28
Wet Season									
19	86	2.80	1.44	1.39	0.05	1.75	−0.31	3.55	−2.11
20	90	4.42	2.05	1.79	0.26	1.96	0.09	3.08	−1.03
21	95	5.84	(2.89)	2.32	0.57	2.02	0.87	3.65	−0.76
22	100	10.58	(3.86)	2.18	1.68	2.36	1.50	3.19	0.67
23	101	9.25	(3.50)	2.79	0.71	2.41	1.09	—	—
24	103	4.80	1.95	1.62	0.33	1.59	0.36	—	—
25	107	4.09	1.86	2.44	−0.58	2.15	−0.29	—	—
26	109	4.59	1.88	2.28	−0.40	1.32	0.56	—	—
27	111	3.03	1.70	2.40	−0.70	1.57	0.13	—	—
Dry Season		1936							
28	114	2.18	1.48	1.81	−0.33	1.96	−0.48	—	—
29	116	2.52	1.49	1.91	−0.42	2.04	−0.55	—	—
30	123	0.55	0.47	0.98	−0.51	1.14	−0.67	—	—
31	128	1.48	0.78	1.35	−0.57	1.14	−0.36	—	—
32	131	0.90	0.65	0.66	−0.01	0.69	−0.04	—	—
33	132	2.94	2.07	1.93	0.14	2.18	−0.11	—	—
Means									
Wet Seasons		5.22	2.61	2.22	0.39	2.07	0.54	2.79	−0.18
Dry Seasons		1.25	0.84	1.15	−0.31	1.08	−0.24	1.18	−0.34

Note: Brackets in Column 4 denote values for corrected effective rainfall greater in magnitude than 2.80 ins., which represents the *saturation capacity* of the soil.

It will be noticed in the table and the diagram that the values for calculated effective rainfall on many occasions in the wet seasons exceeded the mean saturation capacity value for the soil of the plots which is 4.06 ins., or 2.80 ins. above the wilting coefficient value (Table III). This excess amount of accumulated rain may be regarded either as run-off water or as water that penetrates deeply below the rooting zone, and its amount should therefore be subtracted from the calculated effective rainfall. Its elimination affords a further correction to the effective rainfall data and, when applied to data already corrected for torrential showers as shown in the diagram (lower effective rainfall graph), it brings the data into closer agreement with those for available soil moisture directly determined (particularly for the fallow plot) by cutting off the peaks above the 2.80 ins. level that occur in the middle of the wet seasons of 1934 and 1935. With this further correction, the correlation coefficient between corrected effective rainfall and available soil moisture becomes 0.910 which is highly significant at the 0.1 per cent. point. Indeed the two graphs depicting available moisture content for the fallow plot and effective rainfall corrected for torrential showers and for super-saturation, are nearly identical.

Summary

1. This article discusses indirect methods having bearing on the evaluation of available moisture in the soil (sometimes termed effective rainfall) from daily rainfall records. Their applicability is tested by reference to data obtained on three sets of plots at the College Farm whose moisture and nitrate relations were considered in a previous article.

2. The fate of rain water falling on the land is followed with regard to evaporation, run-off, percolation and retention within the rooting zone where it is partly available to plants.

3. Mohr's formula for evaluating evaporated water which involves monthly rainfall values is considered and applied in modified form to the College data. The modified formula is :

$$E = 4 + 1/8\ R \text{ (ins.)}.$$

4. Data obtained by Mohr's method are compared with those derived from the classification of rain-showers into arbitrary categories mentioned in the previous article, namely, rate above 0.75 ins. per hour (run-off rain), rate between 0.75 and 0.41 ins. per hour (soaking rain), and rate below 0.41 ins. per hour (evaporated rain). The data derived by each method show a similar order of magnitude.

5. Leake's method of evaluating effective rainfall from daily rainfall figures is described and applied to the College data.

The method is based on the assumption that a certain fraction of each daily rainfall becomes effective during the next day and augments the rainfall of that day, and so on. The fraction lost is assumed to represent run-off, deep penetration below the rooting-zone, evaporation and fixation in an unfree condition by the soil.

6. The results obtained are compared with data for available soil moisture directly determined periodically on plot soil samples. Best agreement was obtained when torrential rain (showers of rate above 0.75 ins. hr.) was discarded and effective rainfall calculated on the residue. Even then the method somewhat overestimated available soil moisture during the wet season and underestimated it during the dry season.

7. A further modification was effected by discarding effective rainfall in excess of that required to saturate the soil as decided by its saturation capacity based on pore-space measurements. The final results indicate that Leake's method, thus modified, may furnish a fairly reliable measure of available moisture, at least for uncropped sandy soil.

8. The final recommendation for treatment of daily rainfall data for the purpose of estimating available soil moisture may be summarised as follows :—

(i) Add together all daily rainfalls of rate 0.75 ins. per hour or over, assumed to comprise run-off water, and subtract their total amount from the daily rainfall values.

(ii) Apply Leake's method of summation to the residues of daily rainfall.

(iii) Determine the mean apparent and the mean true specific gravity of the soil comprising the rooting zone by weighing constant-volume soil samples collected *in situ* without disturbing the natural structure of the soil.

(iv) Calculate from the results the mean total pore-space volume percentage of the soil ; this provides a measure of the saturation capacity.

(v) Determine the wilting coefficient of the soil either directly in plant cultures or derive it from other soil moisture constants determined in the laboratory. (These constants are customarily expressed as weight percentages on oven-dry soils). Convert the result to volume percentage by multiplying by apparent specific gravity.

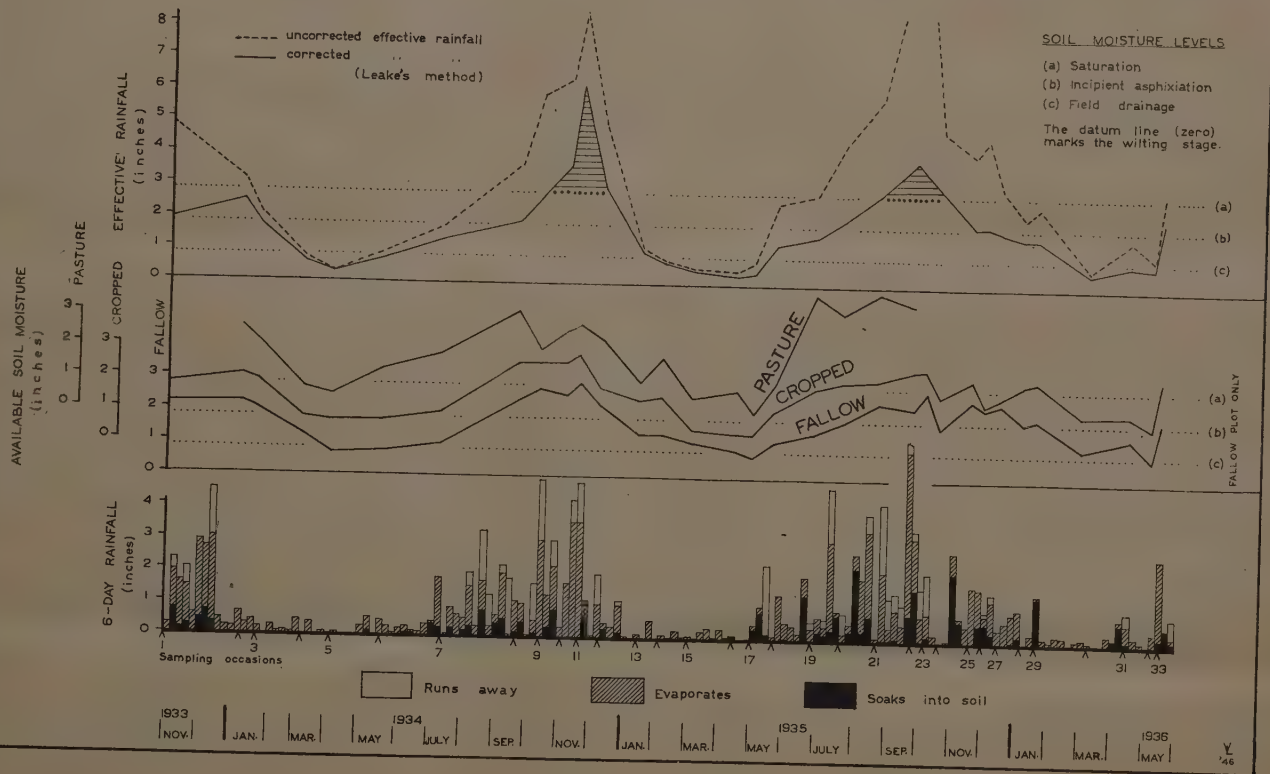
(vi) Subtract wilting coefficient from saturation capacity and convert the residue to inches of rain by multiplying by the thickness (inches) of the rooting zone and dividing by 100.

(vii) Discard the surplus of all values derived by Leake's method in (ii) that are numerically greater than the result obtained in (vi).

(viii) The final data thus obtained are believed to provide an approximate assessment (in inches of rain) of *available soil moisture* from day to day. They may be converted to weight percentages on oven-dry soil by dividing by thickness of rooting zone, then by apparent specific gravity and multiplying by 100.

COMPARISON OF AVAILABLE SOIL MOISTURE DIRECTLY DETERMINED WITH EFFECTIVE RAINFALL CALCULATED BY LEAKE'S FORMULA

DATA FOR PLOT SOILS (FALLOW, CROPPED, PASTURE): COLLEGE FARM: 1933-'36



Explanation of the Diagram

The main results obtained in this investigation are shown in the accompanying diagram.

(1) *Total rainfall.*—This is represented at the base of the diagram by vertical columns at 6-day intervals.

(*a*) The unshaded top part of each column represents run-off, estimated as torrential showers having rate above 0.75 ins. per hour.

(*b*) The cross-hatched part represents evaporated water, estimated as light showers below 0.41 ins. per hour.

(*c*) The blackened part represents penetrating water stored within the rooting zone, estimated as medium showers of 0.74 to 0.40 ins. per hour.

(2) *Effective rainfall.*—This is shown by the upper (dotted) line based on data derived by Leake's method from daily rainfall records. The next line below is based on data corrected by discarding torrential rain (over 0.75 ins. hr.) from the daily rainfalls. The main peaks in this line are truncated by the horizontal line representing the saturation capacity of the soil. Effective rainfall above this amount either runs away or penetrates deeply below the rooting zone.

(3) *Available soil moisture.*—Results obtained directly on periodic field samples, corrected by subtracting the wilting coefficient value, are shown for fallow, cropped and pasture plots, by three graphs whose datum lines (wilting point levels) are equally spaced to avoid overlap.

Close resemblance may be noted between these graphs (especially that for the fallow plot) and the corrected effective rainfall graph derived by Leake's method.

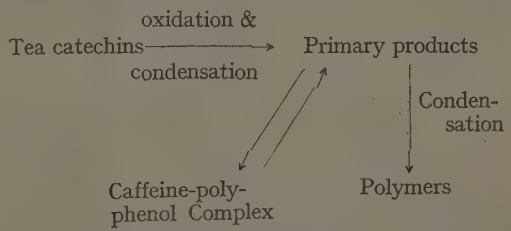
RECENT DEVELOPMENTS IN CHEMISTRY OF TEA

In a paper read to the Agricultural Group of the Society of Chemical Industry Dr. E. A. Bradfield stated that :—

"An essential stage in the manufacture of black tea from the leaves and leaf buds of *Camellia thea* was the so-called 'fermentation' of tea, in which the main chemical changes affected the polyphenols of the green leaf and determined the colour and flavour of the liquor which may be prepared by infusing the resulting black tea. In reviewing the recent studies of tea, it was convenient to group the results around this enzymic process, dealing successively with the substrate, the enzymic reaction and the product.

Although gallic acid free or combined had long been known as a constituent of black tea, it was only with Tsujimura's work that a real knowledge of the characteristic polyphenols of tea began. From Japanese green tea this author isolated, albeit in low yield l-epicate-chin, l-gallocatechin and l-gallocatechin gallate. In a more recent investigation in which the method of partition chromatography had been employed, it was found that the ether-soluble fraction of the polyphenols of Ceylon green (unfermented) tea (about 80 per cent. of the total polyphenol) included, in addition to Tsujimura's three substances, dl-gallocatechin or its epimer, l-gallocatechin gallate, a gallate of a catechin not yet fully identified, and two other substances, one of which is a catechol derivative. No gallotannins were found. Approximately two-thirds of the tea catechins existed in combination with gallic acid and, moreover, the pyrogallol derivatives considerably outweighed the catechol derivatives.

Workers in the early part of this century found that the oxidation of the tea catechins under the influence of an enzyme was the essential reaction of tea fermentation. Detailed study by Roberts and by Lamb and Sreerangachar had thrown much light on the enzyme reaction, and had gone far towards establishing the tea enzyme as a copper-containing polyphenol oxidase belonging to the same group as the polyphenol oxidases of potato and mushroom. The primary oxidation products of the tea catechins were o-quinones, which undergo condensation. Evidence for the existence of products of high molecular weight in black tea infusions was provided by dialysis, and consideration of the groups of polyphenols isolable by this method and by ethyl acetate extraction led to the following scheme as representing the reactions taking place in tea fermentation :



The quality of a black tea liquor, as judged by the tea taster depended primarily on the relative proportions of unchanged tea catechins, primary products and polymers. A high proportion of primary products gave a liquor of good colour, powerfully astringent and creaming down well. Too high a proportion of polymers gave dull brownish liquors, lacking in strength."

AMAZONIAN JUTE (*Corchorus spp.*) FOR COFFEE BAGS

The recent history is told in *Agric. Amer.*, 1945, **5** : 23-6 of the production of Brazilian jute which now occupies an area of about 16,000 acres along the Amazon river and its tributaries. The part played by research in developing this new industry and the still primitive cultivation methods employed are described.—(*Abst.* 1241 in *Hort. Abst*, **15**, 167, 1945)

A COMPARISON OF THREE VARIETIES OF DERRIS ELLIPTICA

BY

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Introduction

For the production of the insecticide rotenone, there is a choice of the genus, variety, and strain of plant which may be used. Thus, rotenone can be profitably produced by certain species of either *Derris* or *Lonchocarpus*, and minor possibilities are species of *Tephrosia*, *Mundulea*, and *Pachyrhizus*. Within the first 2 genera, in which the root is the principal source of rotenone, *D. elliptica* (Wall.) Benth. and *L. nicou* (Aubl.) DC. are the most promising, and of the former there are several varieties among which considerable differences exist. In this report 3 varieties of *D. elliptica* are compared.

There are several criteria upon which comparisons of these varieties are based, namely: (i) yield of root; (ii) quality of root as measured by content of rotenone or of rotenone plus rotenoids (1), and (iii) the derived criterion, rotenone or other quality unit per plant or unit area. Minor points such as ground cover value, nitrogen-fixative power, and amount of cuttings produced by the different varieties were not considered.

In this experiment the following objectives were attained: (i) to compare three *Derris* varieties; (ii) with two of the varieties to test the effect of diameter of cutting on the quantity and quality of the root and (iii) to gain some idea of the necessary number, size, and shape of plots that should be used in experiments with *Derris*.

Experimental materials and design

The 3 varieties of *Derris elliptica* were: Sarawak Creeping, Changi No. 3 (Rio Piedras clone), and St. Croix.† The Sarawak Creeping and Changi No. 3 varieties were introduced in 1939 by the Agricultural Experiment Station of the University of Puerto Rico at Rio Piedras. Several of the cuttings of Sarawak Creeping took root at Rio Piedras but only one cutting of Changi No. 3 became established. The present supply of these two varieties of *Derris* was secured by vegetative propagation of these original plants. Therefore, it is not entirely certain that the Sarawak Creeping variety is all of one clone but it is known that the Changi No. 3 is one clone. The St. Croix variety was obtained from the Agricultural Experiment Station in St. Croix, U.S. Virgin Islands, where the three original plants of *D. elliptica* were grown from seed introduced from Java in 1932. Cuttings from these three plants were planted at Mayaguez in 1935 but no segregation was made. One of the selections with different leaf characteristics was later found to be low in rotenone and was therefore discarded. The other two selections, identical in leaf and stem characteristics, were distinguished by the reaction of several roots of each plant to the Durham test. It is not at all certain that this procedure is valid for the separation of the material into two clones, especially if the rotenone contents are not very different from each other. In other words, the great overlapping of rotenone contents and the qualitative nature of the test used probably led to the inclusion of many plants in each clone that really belonged to the other clone. The quality of the three varieties as shown in previous work is indicated in Table 1.

The field used for this varietal test was plowed and disked, and surface drainage established. Rows were then opened with a middle-buster plow. From October 5 to 16, 1940, plants 6 to 9 months old, pruned to 6-inch stumps, were planted at 2-foot intervals in rows 3 feet apart. Each variety was replicated 10 times in plots of 10 rows of 18 plants each. Exclusive of border plants, the experimental plots were 8 rows of 14 plants each. On May 2 and 3 of the following year a commercial fertilizer, formula 12-10-16, was applied at the rate of 800 pounds per acre by scattering adjacent to the rows and covering lightly with soil. During the growing period plants that died were replaced, weeds were kept at a minimum, and the vines were confined within plot limits. The roots were harvested between May and September, 1943 by removing the vines, plowing 16 inches, followed by collection of the roots while using potato forks to break up the clods of soil. The roots were washed, split, dried, and chopped before being sampled for rotenone analysis.

Separate samples were also taken for moisture determination of the chopped air-dry root so that all root yields could be calculated on the same basis. Although this last step would be justified if the material from different plots were at widely different moisture levels at the time yield data were recorded, it happened that the moisture contents of the samples were so nearly equal that this step was unnecessary; the same results were obtained from the original data uncorrected for differences in moisture content.

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†Other Changi No. 3 selections obtained in Singapore and propagated subsequently in Sumatra and then in Panama are also growing at this station. Unfortunately, these were received too late to be included in this experiment. On the basis of preliminary results, these particular selections are both high in rotenone (around 8 per cent.) and high in yield per acre. Their growth habit, more erect than the trailing Changi No. 3 from Rio Piedras, indicates that the two are not the same variety.

Table 1

Quality of root of three varieties of *D. elliptica*

Variety	Source of roots	Year harvested	Age at harvest	Culture	Rotenone
			Mo.		*Per cent.*
Sarawak Creeping	5 plants, Rio Piedras	1939	36	Trellised	4.7
	Ammonium sulfate Experiment, Mayaguez	1938	25	Trailing	4.9
	Trellised-trailing Experiment, Mayaguez	1939	27	Trellised	3.7
	Regional tests, Mayaguez and Caguas	1941	27	Trailing	7.0
Changi No. 3 ...	6 plants, Rio Piedras	1937	36	Trellised	4.4
	Control plants of starvation experiment, Mayaguez ...	1937	27	Trellised	5.0
St. Croix ...	15 plants, Mayaguez	1937	36	Trellised	3.1
	Age-at-harvest experiment, Mayaguez	1941	24	Trailing	0.7 to 2.6

Results

The St. Croix variety produced 2,948 pounds of dry root per acre which was greater by high significance than the root yield of Changi No. 3, 1,264 pounds per acre This, in turn, was significantly greater than the root yield of Sarawak Creeping, 1,028 pounds per acre.

With regard to root quality as measured by the rotenone content, (2) the Sarawak Creeping variety led with a mean rotenone content of 5.5 per cent. This was greater by high significance than the rotenone content of the root of Changi No. 3, 4.1 per cent. The root of the St. Croix variety was poorest with 2.0 per cent. As measured by rotenone-plus-rotenoids content, the order was the same but the range greater: Sarawak Creeping, 14.7; Changi No. 3, 7.4; St. Croix, 5.1 per cent. The ratios of rotenone to rotenone plus rotenoids were 0.38 and 0.39 respectively, for the Sarawak Creeping and St. Croix varieties; these two were not significantly different, but the Changi No. 3 had a significantly higher ratio of 0.55. This indicated that even at equal rotenone levels the Sarawak Creeping and St. Croix root would be insecticidally superior to that of Changi No. 3 (3).

In the evaluation of these three varieties it was found that, under the conditions of this experiment, the St. Croix variety produced by far the most root and the Sarawak Creeping by far the best quality root. The product of root yield and rotenone content was calculated in pounds of rotenone produced per acre with the following results: St. Croix, 58.6; Sarawak Creeping, 55.6; and Changi No. 3, 51.0 pounds of rotenone per acre. The differences between St. Croix and Sarawak Creeping and between Sarawak Creeping and Changi No. 3 were not significant but the difference between St. Croix and Changi No. 3 was almost highly significant. Calculation of the correlation or the regression between yield and quality showed no significant relationship for any of the varieties.

This experiment showed that the Changi No. 3 variety (Rio Piedras) was inferior in the most important respects to the St. Croix and Sarawak Creeping varieties. The two latter varieties had certain advantages: The St. Croix variety produced more root per acre. This may be an advantage if a mechanical harvester were used because the roots would be stronger and less easily lost in the soil. Also, the plants of the St. Croix variety had a large root system which was extremely vigorous and sturdy; there may be more basis for hope to raise the rotenone level of this low-rotenone root. The chief disadvantage of this variety was that the root was so low in rotenone percentage as to be commercially unacceptable. The Sarawak Creeping variety produced a smaller quantity of root but it was of higher quality and therefore would be cheaper to dry and grind. Moreover, it was of a quality acceptable to the trade.

Correlation of results of chemical determinations of quality

Considerable controversy has existed over the possibility of evaluation of rotenone-bearing plant material by means other than a complete analysis for rotenone. One of the methods, the Gross-Smith colorimetric test, has been used with some success (1) in that it gives a result fairly proportional to the rotenone content within varieties and can be used instead of rotenone analysis with a consequent saving of time and materials. The test is of considerable value in work in which the samples are small or a great number of assays are to be made. It is also true that the colorimetric determination gives results that are somewhat more closely correlated with toxicological value than those obtained by rotenone analyses.

The extent to which the results obtained by these two chemical determinations are correlated was measured by calculating the correlation coefficient between the rotenone content and the rotenone plus rotenoids value as determined

colorimetrically. The coefficients in this experiment were all highly significant; namely, 0.865, 0.911, and 0.933, respectively, for the varieties Sarawak Creeping, Changi No. 3, and St. Croix. Combining the results for the 3 varieties gave a correlation coefficient of 0.911. This, then, is further confirmation of the worth of the colorimetric method for the evaluation of rotenone-bearing material in samples of varieties of which the analyst knows something about the proportion of rotenone to rotenone plus rotenoids.

Table 2

Regression between rotenone content and rotenone plus rotenoids and total chloroform extractives of 3 *Derris* varieties*

Variety	Equations†
Sarawak Creeping ..	R=0.25 C+1.66=0.25 E+1.30
Changi No. 3 ..	R=0.77 C−1.45=0.53 E−0.37
St. Croix ...	R=0.37 C+0.07=0.28 E+0.28

*All t values indicated highly significant regression coefficients.

† In these equations R=rotenone percentage, C=rotenone plus rotenoids colorimetric value, and E=total chloroform extractives.

It is also interesting to note the correlation between rotenone and total chloroform extractives. The latter value was obtained by evaporating an aliquot of the chloroform extract (made in the rotenone determination) and drying to constant weight at 105°C. The correlation coefficient, 0.991, for the three varieties was highly significant. The ratios and standard deviations of rotenone content to total chloroform extractives for the varieties were: Sarawak Creeping, 0.337±0.020; Changi No. 3, 0.480±0.018; St. Croix, 0.334±0.021. This shows that the total chloroform extractives can also be used as an estimate of the rotenone content in samples of varieties of which the analyst knows something about the ratio. These same data were used for the calculation of the regression coefficients between rotenone percentages (R), and rotenone plus rotenoids colorimetric values (C), as well as total chloroform extractives (E). The equations are given in Table 2. Using these equations for the calculation of rotenone percentages from the other 2 values gave results differing by no more than 0.2 per cent. of rotenone.

Effect of size of cutting

The influence of the diameter of the cutting on the yield and quality of *Derris* was previously reported by Moore and Jones (4). In that experiment the large cuttings of Sarawak Creeping ranging from 40 to 12 mm. in diameter were the underground stems of mature plants from which the tops and roots were removed. These are sometimes referred to as parent cuttings. Two other classes were from vines (stems) 14 to 8 mm. in diameter, medium, and 8 to 5 mm. in diameter, small. The greatest mortality of plants was of those from small cuttings. Harvested after 31 months in the field the yields were 1,117, 1,094, and 1,010 pounds per acre for the plots from large, medium, and small diameter cuttings, respectively. The differences were not significant.* With regard to total chloroform extractives of the root, the small and medium classes were equal and significantly higher than that from the large series. Likewise, the rotenone content of the material from the plants from large cuttings was lower than that from the other two series. Therefore, it was concluded that small and medium diameter cuttings were about equal, except for higher mortality of the small, and were somewhat superior to plants from parent cuttings.

In the present varietal experiment the effect of size of cutting on the yield and quality of root harvested was again studied. The St. Croix material was not considered in this part of the experiment. In five of the Sarawak Creeping plots and in all of the Changi No. 3 plots, 5 of the 10 rows were planted with large cuttings, greater than 8 mm. in diameter, and the other half with small cuttings, 8 mm. or less in diameter. Both sizes of cuttings used were leafless and none had been previously used as propagating material. These subplots were then harvested as separate treatments to obtain the yield of root and the percentage of rotenone plus rotenoids.

Upon analysis of the data for yield of root, quality, and yield of rotenone plus rotenoids per plot, no significant differences were found. However, the large cuttings were superior to the small cuttings with respect to mortality. This conclusion is important because the producer can expand plantings at a much greater rate using all sizes of propagating material with the assurance that the plants will not vary with the diameter of cutting used. This is also important to the propagator who has an outstanding plant selection which must be expanded as rapidly as possible.*

The required number and optimum size and shape of replicated plots

The foregoing experiment, although primarily designed for the estimation of varietal differences, consisted of 10 replications of each treatment, each being 112 plants. Data were taken by subplots in such a manner that a rough estimate could be made of the optimum number, size, and shape of replicates necessary in this type of experiment to demonstrate the significance of differences among treatments. Obviously, the number and size of replications necessary to furnish statistical proof of the significance of differences between treatments depends on the magnitude of the differences among

*In connection with this point, the rapidity with which derris plantings can be expanded, it has been shown in more recent work at this station that small leafy cuttings can also be used with the result that mortality is very low and excellent plants are obtained. See *P. R. Expt. Sta. Ann. Rpt.* 1943. (p. 14).

treatments and the variation among replicates of the same treatment. If the experiment is so designed that the differences due to treatment are small, many replicates will be needed to show whether the differences found are significant. Likewise, if the variation among replicates be large, due to heterogeneity of the material, soil or other conditions, many replicates will be needed.

The data for these calculations were obtained from the entire 30 plots and from the west 2 rows of plots which included 4 replicates each of Sarawak Creeping and Changi No. 3. These plots were harvested by fractions of rows, each row of 14 plants being taken as two 5-plant samples and one 4-plant sample. Yields of root were taken and samples prepared for measurement of rotenone plus rotenoids from which rotenone percentages were calculated by means of the ratio of rotenone to rotenone plus rotenoids found for the 30 large plots. The St. Croix variety was not considered in this study. Calculations were made of the number of replicates of various sizes and shapes that would have sufficed to show the varietal differences noted in the foregoing discussion. For this purpose the coefficients of variability and the differences between treatments in terms of percentages of the means were calculated and reference made to Paterson (5) to obtain the minimum number of replicates necessary to demonstrate significant treatment differences at the 5-per cent. level. The results are tabulated in Table 3 for the minimum number of replicates necessary to show significant differences in yield of root, percentage of rotenone, and yield of rotenone.

Table 3

Minimum number of replicates necessary to demonstrate significant treatment differences at the 5-per cent. level in Sarawak Creeping and Changi No. 3 varieties of *Derris elliptica*.

Plot shape and size	Yield of root	Rotenone content*	Rotenone per unit area
	Replicates necessary	Replicates necessary	Replicates necessary
	No.	*No.*	*No.*
Block, 8 plants x 14 plants (10 plots) ..	4	3	18
8 x 14 (4 plots)	3	3	11
5 x 5 ..	3	3	12
4 x 4 ..	8	3	9
2 x 4 ..	9	3	11
Row, 1 x 14 ..	4	3	7
1 x 10 ..	4	3	12
1 x 5 ..	6	3	24
1 x 4 ..	11	3	16

* Calculated from rotenone plus rotenoids except for 8 x 14 plots in which rotenone was measured as such in composite samples.

The data show that the variability was great enough to require a considerable number of replicates in some cases. Apparently, differences in rotenone content of the magnitude 3.9 to 5.6 as in these two varieties can be demonstrated with comparatively few replicates. Therefore, in experimental work involving many replicates, plot samples may be composited in such a manner as to give 3 to 5 samples to be analyzed for rotenone. In most cases more replicates were needed to demonstrate significance of differences in yield in square or rectangular plots than in row plots. It may be that this result is due to the fact that row plots are subject to change in one direction only, along the row, while plots of several rows are heterogeneous in two directions.

Obviously, the value of the information obtained from these data is only qualitative; it can be used only in a rather general way in designing future experiments with similar material. For example, economy of material can be achieved by the use of small row plots with sufficient replications instead of large block plots. In addition to the saving of material and labor, the soil and plant heterogeneity can be minimized. Presumably, part of the variability can be considered as due to variation in the plant material itself. The extent of this contribution to the error is apparent upon comparison of the coefficients of variability for small plots with those for large plots. A great difference in error signifies that the error due to variation of plant material was large in small plots and is minimized when larger plots are used. Such a decrease was apparent in this experiment; in the yield of rotenone per plot, the coefficient of variability decreased from 20.6 per cent. for 1 x 4 row plots to 10.2 for 1 x 14 row plots. This decrease was undoubtedly due to the decrease of variation among the plants as the plot length was increased from 4 to 14 plants. The remainder of the error, as measured by the minimum coefficient of variability obtained, was due to error in harvesting, drying, sampling, weighing, and similar operations. In this experiment this residual error was not excessively large but it is possible that, by using smaller plots, more care could be exercised so that these errors could be reduced even further.

Handling these data in a somewhat different manner Wadley (6) calculated the standard errors for the different-sized plots. "Since analysis showed that difference between large and small cuttings was not significant (half-plot comparison), this could be disregarded, and the half-plot regarded as two independent groups treated alike. It was found that yields varied more over the experiment than did "red test figures. This indicated that any design adequate to compare yields should be good enough for rotenone content."

"It was also found that there was a slight but general tendency for sections within rows to vary more than rows within half-plots. This did not reach significance in any one case but occurred in nearly all comparisons. It indicated that the row

ran along a *gradient* in the field. This is a local rather than a general condition, but agronomists nearly always find long narrow parallel plots more comparable than square ones of the same size because of such conditions. This condition made an evaluation of influence of *length* of row difficult."

"The final analysis was of rows, half-plots and plots within a variety. The Sarawak Creeping variety was more variable than the Changi No. 3 variety, hence is taken as a standard for calculation. The analysis of yields for this variety :

	Degrees of freedom	*Mean square*
Between blocks (distant plots)	3	80.00
Between half-plots within plots (adjacent plots)	4	35.00
Between rows within half-plots	24	6.17

"For figuring results with different combinations, the technique given by Snedecor (7) and Bartlett and Greenhill (8) was used. In a well-replicated small-plot experiment the plot variance seemed more likely to be like that of adjacent half-plots than of distant plots. Hence, 35.00 was taken as estimate of plot variance. If A is the plot variance put on a unit basis and free from error, and B is the sub-plot of row variance, then B=6.17, A=(35.00−6.17)/4 or 7.21. (The divisor is 4 because there are 4 rows in a half-plot.) With *N* plots and *K* rows per plot, the estimated variance of the mean is A/n+B/nk. For example, with 4 plots per treatment and 3 rows per plot, the variance of the mean is estimated as 7.21/4+6.17/12, or 2.31. The estimated standard error is $\sqrt{2.31}$ or 1.52. With 6 plots and 2 rows per plot, estimated variance of the mean is 7.21/6+6.17/12 or 1.71. Other combinations will be easily computed. Single-row plots, where practicable, are indicated as getting the most out of the experimental material, though the use of guard rows will decrease their economy."

"Analysis of the randomized block error, from analysis of variance of rotenone-rotenoid yield, confirms these conclusions."

It was suggested that 10-plant row plots would be a good standard size. Therefore, in work in which border plants are necessary, the plot size would be 36 plants and the number of replicates about 8 to detect reasonably small differences.

Conclusions

The results of this experiment show that the Changi No. 3 variety (Rio Piedras clone) was definitely inferior in important respects to both the Sarawak Creeping and St. Croix varieties. Of these superior varieties the Sarawak Creeping yielded less root of fairly high rotenone content while St. Croix yielded a great amount of root of low rotenone content. The amount of rotenone produced per acre was about the same for the latter two varieties but the St. Croix variety was low in rotenone percentage.

Correlations between rotenone percentage and 2 other criteria, colorimetric and total chloroform extractives, are given.

The effect of size of cuttings, on production of root and on rotenone was shown to be negligible.

Concerning the number, size, and shape of replications required to establish the significance of differences in yield of root, rotenone content, and rotenone yield, it was shown that row plots were more efficient than block plots in that the smaller number of plants required in row plots results in less soil heterogeneity as well as a saving in plant material and labor. Single-row plots of 10 plants each, bordered with non-experimental plants, appear to be suitable for much experimental work; 8 replicates should make fairly precise distribution possible.

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